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SIMULATION OF SYNTHETIC APERTURE RADAR IV: SUMMARY AND RECOMMENDATIONS

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Four experiments were conducted to identify digital feature data base requirements for simulating synthetic aperture radar (SAR). The results indicate that lines of communication and large areal features are the principal cues used in SAR image interpretation. The results also indicate that depiction of small, individual features is required to create a simulation with acceptable realism. These small individual features may be depicted generically without adversely affecting SAR operator task performance. This approach has been proposed by the Defense Mapping Agency (DMA) as the basis for a new Digital Feature Analysis Data (DFAD) product (Level 3-C) to support high-resolution radar simulation. We recommend that the Air Force accept the proposed Level 3-C DFAD specification for SAR simulation.

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SUMMARY

This report summarizes the results of four experiments on digital feature data base requirements for simulating synthetic aperture radar (SAR). These experiments demonstrated that: a) Digital Feature Analysis Data (DFAD) for simulating SAR must have greater density than the current Defense Mapping Agency (DMA) products Level 1 or Level 2; b) the primary cues for SAR image interpretation are lines of communication and large natural features; c) small features must be depicted in the DFAD data base as individual reflectors but these features may be depicted generically without adversely affecting SAR operator task performance; and d) a data base with reduced individual feature fidelity but moderately high feature density will support SAR operator task performance equally as well as a high feature fidelity, high feature density data base. These results indicate that feature density is a more important factor than feature fidelity in SAR simulation. We therefore recommend that to support SAR simulation, the Air Force accept the newly developed DMA DFAD specification, Level 3-C, which incorporates higher feature density than Level 2 but reduced feature fidelity.

PREFACE

This project was conducted in support of the Air Force Human Resources Laboratory's Research and Technology Plan, of which one objective is Aircrew Training Technology. The goal of this effort is to develop cost-effective strategies and equipment for aircrew training. This research was conducted under Work Unit 1123-33-01, Fidelity Requirements for Sensor Imagery.

We thank the personnel of the 338th CCTS, 96th BMW, 28th BMW, 319th BMW, AAMRL/HE, HQ SAC, HQ DMA, DMAAC, and ASD/ENETV for their help in conducting these investigations. We also thank Maj Michael Seiverding, ASD/YWB, who was project manager for the Level 3-C evaluation.

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I. INTRODUCTION

Simulating Synthetic Aperture Radar (SAR) imagery requires Digital Feature Analysis Data (DFAD) with greater feature density than is currently contained in standard simulator products from the Defense Mapping Agency (DMA). To help determine DFAD requirements for simulating SAR, DMA developed a prototype high-resolution DFAD specification, Level X, which incorporated all ground features which were 10m or larger on a side. The feature density in Level X was much greater than that for standard products such as Level 1, which has a 100m capture criterion, or Level 2 with a 30m capture criterion.

An engineering analysis (TASC, 1985) concluded that Level X would support SAR simulation for Weapon System Trainers (WSTs). Production of Level X in quantity, however, is not practical due to the coverage required by the using major commands (MAJCOMs) and the large number of man-hours required to produce Level X DFAD.

II. SUMMARY OF EXPERIMENTS

Because the engineering evaluation of Level X was intended only to determine whether Level X was adequate for simulating SAR, the minimum DFAD requirements for simulating SAR were not addressed. Four experiments were conducted by the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL/OT), in cooperation with DMA and the Aeronautical Systems Division (ASD/ENETV and ASD/YWB), to determine minimum simulation requirements for SAR. These experiments are briefly summarized in this section. The technical details of the first three experiments are available in Crane, Bell, Kalinyak, Dooley, and Hubbard (1989); the technical details of the final experiment are reported in Crane and Bell (1989).

Experiment 1

In the first experiment, SAR simulations were generated from the high-resolution DFAD prototype, Level X, with a 10m capture criterion and from a current DMA product, Level 2, with a 30m capture criterion. In addition, simulations were also created using two experimental DFADs called Levels Y and Z with 15m and 20m capture criteria, respectively. These simulations were evaluated by SAR-experienced Air Force officers. The simulations generated from the current DMA product, Level 2 (30m), were rated not acceptable. The subject-matter experts also indicated that the 10m capture criterion in Level X was not necessary and that a capture criterion between 15m and 20m was sufficient for acceptable simulation fidelity. DMA determined, however, that simply reducing the number of features included in the DFAD by increasing the capture criterion from 10m to 15m or 20m would not increase DFAD production sufficiently to meet Air Force needs.

Experiment 2

A second experiment was conducted to define what ground features are critical for performing Radar Scope Interpretation (RSI) with SAR imagery. SAR-experienced Air Force officers were asked to identify those features within aerial photographs which they would use to help them locate specified aimpoints. The features most often identified as critical were lines of

communication such as roads, railroads, and canals, and large natural features such as treelines, shorelines, and cultivated fields. Small individual features such as structures were not cited as being task-critical. Nearly all of the critical features are included in DMA Level 2 DFAD.

The major conclusion drawn from Experiment 1 was that a data base density greater than that of the current DMA Level 2 DFAD is required to support SAR simulation. The results of Experiment 2, however, indicated that RSI for SAR is based primarily on the large structures, lines of communication, and natural features which are contained in Level 2 DFAD, rather than the small individual features unique to Levels X, Y, and Z. Based upon the comments of the subject-matter experts in Experiments 1 and 2, it appears that the small individual features contained in Levels X, Y, and Z function primarily to provide the ground detail needed to create a SAR-like appearance within the simulated SAR image. It also appears that regions of densely spaced small features such as residential areas may be used as RSI cues without reference to individual features. If this is indeed the case, then these smaller features might be depicted generically without affecting task performance.

Experiment 3

The hypothesis that small features such as houses and residential streets could be depicted generically without degrading SAR operator task performance was tested in Experiment 3. B-1B Offensive Systems Officers (OSOs) performed a navigation update task for 15 fixpoints using simulated and actual SAR imagery. The SAR simulations were generated from Level X (10m), from Level Y (15m), and from modified versions of Level 2 (30m) and Level 1 (100m) DFAD which were enhanced with generic information in high-density areas (see Crane et al., 1989, for an explanation of the enhancement procedures). In addition, photographs of actual SAR imagery were obtained for each fixpoint. The imagery was presented to the OSOs using the Armstrong Aerospace Medical Research Laboratory's B-1B Engineering Research Simulator at the 338th Combat Crew Training Squadron, Dyess AFB, Texas. Placement accuracy, confidence in placement, and rated acceptability for mission rehearsal were recorded. The results showed that levels of OSO task performance for enhanced Level 2, Level Y, or Level X were not significantly different from each other or from photographed SAR, except that the SAR was rated as more acceptable for mission rehearsal than any of the simulations. Levels of placement accuracy, confidence, and rated acceptability for enhanced Level 1 DFAD were significantly lower than for other DFAD levels and actual SAR.

Taken together, these three experiments indicate that: a) High-density data are required to produce simulations which have the appearance of SAR images; b) these high-density data do not require the degree of ground truth typical of DMA DFAD for features smaller that those currently included in Level 2 (30m) DFAD; and c) high-density areas can be added to Level 2 data through the use of texturing and the breakup of larger areal[1] features into smaller generic features during the data base development process. Based on the results of these first three experiments, Crane et al. (1989) concluded that a high-resolution DFAD product should be specified with high accuracy for lines of communication and other large features, and that less accurate or generic information would be acceptable for small features in high-density areas.[2]

[1]An areal feature is distinguished from a point or line feature in that it is a two-dimensional surface delimited by a surrounding border.

[2]The hypotheis that small features will be depicted generically presumes that if the aimpoint is a small feature it will not be depicted generically nor will small features be generic if they are in the immediate vicinity of the aimpoint and likely to be used as RSI cues. In these cases, higher levels of ground truth will be required.

Experiment 4

Although the first three experiments led to a definition of DFAD requirements for simulating operational SARs, DMA noted that current resource limitations prevented production of sufficient quantities of Level 2 DFAD. Resources for generating the necessary enhancements were also not currently available. As an alternate solution, DMA proposed that high-resolution cartographic products such as 1:250,000 Joint Operation Graphics and 1:50,000 topographic maps could serve as the basis for a high-resolution DFAD. The prototype description of this product, labeled Level 3-C (cartographic), indicated that it would have a data base density similar to that of the enhanced Level 2 DFAD used in Experiment 3. Compared to current DFAD products, however, the number of feature codes would be compressed so that less unique information regarding feature type, height, or reflectivity would be available for each feature. Level 3-C DFAD would be generated using existing DMA cartographic production facilities, thereby greatly increasing the availability of high-resolution DFAD. In addition, the proposed specification would be flexible enough to allow the using MAJCOMs to identify critical features such as aimpoints for insertion into the DFAD.

The objective of the fourth and final experiment in this series was to evaluate the proposed Level 3-C DFAD for use in SAR simulations. This experiment was conducted to ensure that simulated SAR produced using the proposed Level 3-C DFAD specifications would support B-1B OSO performance as well as did the Level X or enhanced Level 2 used in Experiment 3. The detailed description of this experiment is contained in Crane and Bell (1989).

Data bases representing nine of the scenes used in Experiment 3 were developed using DMA-supplied prototype Level 3-C DFAD. Data bases for the same nine aimpoints were also developed using the enhanced Level 2 and Level X DFAD from Experiment 3. Simulated SAR imagery was then generated using AFHRL's Advanced Visual Technology System (AVTS). The details of the AVTS SAR simulation process are described in Ferguson et al., 1989.

The resulting SAR images were transferred to the B-1B Engineering Research Simulators at the 28th Bomber Wing, Ellsworth AFB, South Dakota, and the 319th Bomber Wing, Grand Forks AFB, North Dakota. SAR-experienced OSOs performed a navigation update task similar to that used in Experiment 3.

Overall, placement accuracies using images created from Level X, enhanced Level 2, actual SAR, and Level 3-C were not significantly different from each other. In addition, confidence ratings and ratings of acceptability were not affected by the level of DFAD used to create the simulator data base.

III. CONCLUSIONS

This series of experiments evaluated the effects of DFAD density and feature accuracy on the quality of SAR simulations. The data from these experiments indicate that major lines of communication and large areal features are critical RSI pointers which must be represented within the DFAD. These experiments also indicate that feature density must be greater than current Level 1 or Level 2 DFAD densities for acceptable SAR simulation. The feature density of the prototype Level 3-C DFAD is sufficient to produce an acceptable simulation of the current B-1B SAR. In addition, the compression of feature identifiers characteristic of Level 3-C DFAD did not adversely affect performance. This indicates that feature density is a more critical variable than feature uniqueness in simulating small features for B-1B SAR.

IV. RECOMMENDATIONS

The following recommendations are provided regarding Synthetic Aperture Radar (SAR) simulation requirements:

1. That the Air Force accept the proposed Level 3-C as a high-resolution Digital Feature Analysis Data (DFAD) product to support SAR simulation for the B-1B and F-15E Weapon System Trainers.

2. That DMA produce Level 3-C DFAD to meet current SAR simulation requirements.

3. That DMA and the Air Force begin now to address next-generation sensor simulation requirements.

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